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Spatio-temporal Masking: Hyperacuity and Local Adaptation

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Our development of an ideal-observer framework and a test-pedestal methodology for modeling vision without the numerous assumptions of previous models has provided a comprehensive understanding of the spatio-temporal characteristics of human vision. The methodology encompasses a limited set of test stimuli with a multiplicity of pedestals to facilitate the comparison of performance across many psychophysical tasks. For example, it is shown that vernier acuity can generally be predicted from an individual's contrast discrimination threshold. For the conditions under which contrast discrimination predictions break down, a detailed modeling of later stages of visual processing is required. As a result, specifications for a vision modeling tool have been developed to guide the creation of a comprehensive vision modeling environment. As our models of visual function have matured, we have applied them to practical issues such as image compression and image quality. Consideration of properties of human vision is essential if the image compression needed for new technologies such as HDTV are to avoid sacrificing image quality. The success of the test-pedestal methodology has also lead us to record human visual evoked potentials so that we may integrate our psychophysical data and models of vision with underlying physiological mechanisms.

vision models, human vision, image compression, image quality evoked potentials, ideal observer

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Progress report for AFOSR-89-0238 **February 5, 1992**

Title: Spatio-temporal Masking: Hyperacuity and Local Adaptation.
Period covered: January 1, 1990 - December 31, 1991

Objectives of the research effort.

a. Develop robust "ideal-observer" methods for modeling spatial vision with fewer assumptions than previous models. The proposed test-pedestal framework for spatio-temporal interaction uses the same test pattern with multiple pedestals in different phase relationships to learn about the properties of the underlying mechanisms.

b. As part of our work on improving models of spatial vision I have been meeting with a group of Berkeley faculty to organize a major effort to develop a user-friendly modeling environment.

c. An important direction of our Air Force research is to take our models of human vision and apply them to several areas of applied image processing (image compression and image quality), a timely topic with the coming of high definition television and other digital image technologies.

d. We desire to connect our psychophysics research to the underlying physiological mechanisms. In this regard we have found that new techniques are needed to learn about nonlinear visual processing so we have also devoted a significant effort to improving methods for the nonlinear analysis and source localization of visual evoked potentials and other biopotentials.

Summary of Research Effort.

The past two years have been very productive for my research group. Based on AFOSR support we have 15 papers either published or in press. I am including one copy of each paper with this report. If I were to summarize the work done on each paper this document would become excessively lengthy. Instead, this summary will be restricted to the following: 1) A general summary of our research on connecting the insights from human vision to applied topics (image compression and image quality), 2) A more detailed summary of our work on vernier acuity to show our approach to modeling. An outgrowth of this research is our collaboration with other Berkeley faculty to develop a user-friendly environment for modeling vision. 3) A summary of our work measuring biopotentials. In order to connect our psychophysical data and models to underlying physiological mechanisms we have executed several visual evoked potential studies and have developed new methodologies for studying nonlinear physiological processing.

1) Image compression and image quality. Seven of the papers that have been written during the two year period of this report are connected with the assessment of image quality. The field of image compression is growing very rapidly because of the arrival of HDTV, teleconferencing and picture phone and also because of developing standards by committees such as JPEG and MPEG. The standards developed by JPEG and MPEG are ideal for the vision research community. The quantization algorithm is based squarely on properties of the human visual system. What is needed is much more information from researchers in human vision on how to do context dependent image compression and image quality evaluation. That is, different types of image degradation will be more or less visible depending on the local context of the image. This is the topic of visual masking. One of the directions of both our basic research and our applied research is to show that the calculation of masking magnitude is more difficult than commonly believed. We are able to demonstrate situations with strong pedestals in both in space and in time where the masking is minimal. In particular as shown in (Hu, Klein & Carney, reference #14) there the masking of a thin line by a uniform flash is very localized in time and limited in strength. Based on these results we have calculated that the human visual system is able to take in much more information than is transmitted by normal compression schemes. We believe that our research is relevant whenever the goal is to achieve perceptually lossless compression.

We would also like to highlight the paper by Klein & Beutter (1992, reference #7) because it has caused a stir in several fields. In image compression (and image processing in general) one wants to use filters that are localized in both space and spatial frequency. Gabor once made a claim that for real-valued functions, the Hermite functions (Hermite polynomials times a Gaussian) minimize the joint space-spatial frequency uncertainty. What we showed was that for the class of functions that are an m^{th} order polynomial times a Gaussian, the Hermite functions *maximize* the joint uncertainty. Individuals from different disciplines have indicated the usefulness of this result (e.g. I have been informed that Hermite functions characterize the profile of a laser beams and based on Gabor's work it had been thought that this was a *good* profile).

2) Vernier acuity and modeling. Using the test-pedestal paradigm, we initially established a connection between vernier acuity and contrast discrimination using sinusoidal stimuli (Hu, Klein & Carney, 1992, reference #16). Rather than using a complex model with many assumptions we showed that to first order vernier acuity was well predicted by contrast discrimination thresholds when both tasks are expressed in the same contrast units. These results can be explained by both tasks using common underlying mechanisms. However several notable exceptions were evident, at high spatial frequencies vernier thresholds degraded faster than expected from contrast discrimination data. Moreover, the tvi slope was always shallower for the vernier task. We have been exploring other stimulus configurations such as different line lengths and central gaps in both tasks to determine the source of the deviations from predictions based on contrast discrimination. At high spatial frequencies, decreasing grating length hurt contrast discrimination threholds but actually improved vernier acuity. The vernier task is presumably performed by oriented mechanisms, the long grating possibly diluted or smeared out the orientation cue which reduced the effectiveness of oriented mechanisms. The difference in tvi slope is likely due to the use of oriented mechanisms. If vernier acuity involves mechanisms oriented away form the pedestal orientation it would avoid some of the contrast masking effects observed for the contrast discrimination task, thereby resulting in a different tvi slope.

We are now also comparing vernier acuity and grating detection threholds in the presence of oriented masking gratings. The masks have large effects at orientations somewhat different from the vernier target grating. This masking effect is greatly reduced in the grating detection task. In summary, vernier acuity for the most part is well predicted by contrast discrimination. Future models of vernier acuity will have to consider properties of later stage of processing in order to account for performance where contrast discrimination does not predict vernier acuity. Such models will likely include multiple mechanisms as different spatial scales, orientations, and densities. We have spent some time working with various modeling tools, such as the early vision emulation software (EVE), Mathematica and Matlab, but have found each lacking in ease of use or flexibility. Our frustration with these tools along with several other faculty members at UCB lead to regular meetings on the requirements for a powerful vision modeling environment. Besides Thom Carney and myself, participants in this group include Jitendra Malik, Marty Banks, Ted Cohn and Gordon Legge (who was on sabbatical here). Having enumerated the required capabilities for such an environment to be useful to the vision community at large, we are now preparing a proposal for implementing a comprehensive vision modeling tool. Such a tool would prove invaluable in extending our understanding of spatial and temporal vision.

3) Connecting psychophysics to physiology: The visual evoked potential. The power of the test-pedestal approach for revealing underlying mechanisms lead us record visual evoked potentials (EP) to such stimuli with the goal of cortical functional localization. The temporally varying test pattern was identical across conditions, the different static pedestal patterns determined the stimulus condition, dynamic vernier, motion, contrast modulation or counterphase sinewave. This approach has the advantage that the test signal that generates the EP was identical across conditions. The results were compitable with psychophysical results described above but functional localization was not possible with the limited number of recording channels available to us (ARVO 1990).

More recently we teamed up with Anthony Norcia and Peter Wong (ARVO 1991) who had collected EPs to a variety of stimulus categories, vernier jitter, color, onset/offset, and counterphase patterns using a 21 electorde recording array. Our analysis of the data revealed some cortical specificity for the type of stimuls pattern. Unfortunately, the stimuli were not selected according to the test-pedestal paradigm which complicated comparisons across stimulus conditions.

Based on these experiences we have proposed to localize in space and time the multiple cortical sources of the EP by combining the multi-input analysis technique developed by Erich Sutter with large EP recording arrrays and careful stimulus control. We expect to track the processing of cortical information in time and time and relate it to stimulus dimensions such as color motion and form, thereby furthering our understanding of cortical functional organization. In connection with this plan we have developed improved methods for estimating the linear and nonlinear kernels from multi-input white noise experiments (Klein, 1992, reference #8).

Published and In Press articles. (January 1, 1990 - February 4, 1992).

One copy of articles 1 - 16 has been enclosed with this technical report.

1. Klein, S. A. (1990). High resolution and image compression using the discrete cosine transform. *SPIE: Human Vision and Electronic Imaging, Methods and Application.* **1249**, 135-146.
2. Klein, S. A. and Carney, T. (1990). How many bits/min^2 are needed for the perfect display? *Society for Informational Display 90 Digest* **21**, 456-459.
3. Klein, S. A., Casson, E, and Carney, T. (1990). Vernier acuity as line and dipole detection. *Vision Res.* **30**, 1703-1719.
4. Klein, S. A. & Carney, T. (1991). "Perfect" displays and "perfect" image compression in space and time. *Human Vision, Visual Processing and Digital Display II.* Bernice E. Rogowitz, Jan P. Allebach and Michael Brill, Editors, Proc. **SPIE 1453**, 190 - 204.
5. Klein, S. A. & Carney, T. (1991). How the number of required grey levels depends on the gamma of the display. *Society for Informational Display 91 Digest* **22**, 623-626.
6. Carney, T. & Shadlen, M. (1992). Binocularity of early motion mechanisms: comments on Georgeson and Shackleton. *Vision Research* **32**, 187-191.
7. Klein, S. A. & Beutter, B. (1992). Minimizing and maximizing the joint space-spatial frequency uncertainty of Gabor-like functions. *J. Opt. Soc. Am. A.* **9**, 337-340.
8. Klein, S. A. (1992). Optimizing the estimation of nonlinear kernels. *Nonlinear Vision.* Eds. Robert B. Pinter and Bahram Nabet. In Press, CRC Press.
9. Klein, S. A. (1992). Channels: Bandwidth, channel independence, detection vs. discrimination. (Chapter in <u>Channels in the visual nervous system: Neurophysiology, psychophysics and models</u>. Blum, ed.)
10. Klein, S. A. and Tyler, C. W. (1992). The psychophysics of visual detection: A review of Graham's "Visual Pattern Analyzers". (In press, *Journal of Mathematical Psychology*).
11. Klein, S. A. (1992). An EXCEL macro for averaging data. (In Press, *Behavior Research Methods, Instruments, & Computers*).
12. Klein, S. A. (1992). Image quality and image compression: A psychophysicist's viewpoint. (Accepted for publication, chapter in <u>Visual Factors in Electronic Image Communications,</u> MIT Press).
13. Klein, S. A. (1992). Will robots see? (Accepted for publication, chapter in <u>Spatial Vision in Humans and Robots,</u> Cambridge University Press).
14. Hu, Q., Klein, S. A., & Carney, T. (1992). Temporal luminance masking in the coding of video signals. (In press, *Society for Informational Display 92 Digest* **23**).

Completed research, manuscripts submitted or almost ready to be submitted.

Articles #15 and 16 have been included with this technical report.

15. Carney, T. Shadlen, M. (1992). Dichoptic activation of the early motion system. (Submitted to Vision Research.)
16. Hu, Q., Klein, S. A. & Carney, T. (1992) Vernier acuity and contrast discrimination for sinusoids. (To be submitted to Vision Research).
17. Klein, S. A. & Silverstein, D.A. (1992). How much visual modeling is needed for image processing? (In press, *Human Vision, Visual Processing and Digital Display III.* Bernice E. Rogowitz, Jan P. Allebach and Stanley A. Klein, Editors, Proc. **SPIE 1666**.)
18. Carney, T., Silverstein, D.A. & Klein, S. A. (1992). Vernier acuity during image rotation and translation: Visual performance limits. (To be submitted to Vision Research).

19. Silverstein, D. A. & Klein, S. A. (1992). Discrimination of relative motion. (To be submitted to Vision Research)

List of professional personnel on the project

Stanley A. Klein, Principal Investigator
Thom Carney, Associate Research Specialist
Heidi Baseler, graduate student
Qingmin Hu, graduate student
Amnon Silverstein, graduate student

Interactions: Presentations at meetings

ARVO 1990, 1991

Klein, S. A., Truong, T., Carney, T. "The connection between sinusoid sensitivity and multipole sensitivity: the effect of blur."
Carney, T. Klein, S. A., Levi, D. M. "The effect of 1 and 2 dimensional blur on vernier acuity"
Hu, Q., Klein, S. A., Carney, T. "Comparison of grating vernier acuity and contrast discrimination."
Silverstein, D.A., Carney, T., Klein, S. A. "Vernier acuity during image rotation and translation."
Baseler, H. Carney,T., Klein, S. A. "A test-pedestal paradigm for use with visual evoked potentials"
Silverstein, D.A., Klein, S. A., Carney, T. "The detection of temporal asynchrony in two-dot targets"
Hu, Q., Klein, S. A., Carney, T. "Predicting grating vernier acuity from contrast discrimination: the effect of grating length."
Baseler, H., Norcia, A. M, Wong, P, Carney, T., Klein, S. A. "VEP topograph of perceptually diverse stimuli."
Banks, M., Furuya, M. Klein, S. A., Carney, T. "Front-end limitations on peripheral vernier grating acuity."
Carney, T., Klein, S. A. "Orientation masking of grating vernier acuity"
Klein, S. A., Carney, T. and Levi, D. M. "Dependence of vernier acuity on two dimensional blur."

OSA 1990,1991

Klein, S. A., Beutter, B. Hermite functions maximize the space-spatial frequency uncertainty of Gaboriike functions."
Levi, D, Klein, S. A. "Contrast coding in the amblyopic visual system."
Silverstein, A. D. Klein, S. A. "Relative motion discrimination"